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AN INTERACTIVE PRODUCTION CONTROL TRAINING MODEL FOR A NARF SHO--ETC(U)
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# AN INTERACTIVE PRODUCTION CONTROL TRAINING MODEL FOR A NARF SHOP

Research Report No. 81-8

by

John C. Gilmour
and
Thom J. Hodgson

June, 1981

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This paper ~~is~~ a report on an interactive production control training model for a Naval Air Rework Facility (NARF) Shop. The system is an interactive shop simulator which allows production control decisions to be made by the user. The objective is to provide a training vehicle for production control decision making. The report includes a "Users' manual" and program listing.

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# ABSTRACT

This paper is a report on an interactive production control training model for a Naval Air Rework Facility (NARF) Shop. The system is an interactive shop simulator which allows production control decisions to be made by the user. The objective is to provide a training vehicle for production control decision making. The report includes a "users' manual" and program listing.

## I. INTRODUCTION

The Naval Air Rework Facility (NARF) at Jacksonville Naval Air Station is an industrial plant with some 3,000 employees. It is one of six similiar NARF's located in the United States. Top management officials are Naval officers and the remainder are civilians. The civilian work force includes engineers, planners, administrators, and mechanics representing over 40 different highly skilled trades.

The NARF mission includes maintenance engineering and heavy (depot) maintenance of military aeronautical items ranging from complete aircraft to spare components. By policy, NARF maintenance on all items is a selective process which involves diagnosis of item condition, updating with latest required changes, and limited maintenance rework to recondition the item for another period of service.

The NARF is organized by support services (Engineering, Quality Assurance, Planning, etc.)and the Production Department. The Production Department, with some 2/3 of the civilian workers, is made up of over 100 different shops. These shops, the hardware producing elements of the plant, are organized: some by product (radio shop), some by process (cleaning shop), and some by function (assembly). The shops form an interrelated network through which products flow as the maintenance process proceeds.

The NARF product workload consists of about 50% aircraft. The aircraft are examined (diagnosed), and disassembled as required to permit shop component processing. As a matter of production policy, the processed components are used to reassemble the aircraft, which is then flight tested. About 15% of the NARF workload consists of aircraft engines (which enter the plant as such) and are overhauled and returned to the Navy supply system for issue and reuse. Another 15% of the workload is made up of miscellaneous spare aeronautical components which have been in use and are sent to NARF for required maintenance. After being reconditioned by NARF, these are returned to the Navy supply system for reissue and reuse. The remaining 20% of NARF workload is of a miscellaneous nature including such unplanned items as aircraft repair (repair of damaged aircraft), customer service (on demand), and field modification.

## II. THE NARF SHOPS

This paper deals with a typical NARF shop. The shops under study belong to a class of shops which have the following common characteristics:

1) The bulk of processing on jobs entering each such shop is confined to that shop. This means that a shop functions as a repair station rather than a disassembly, routing, and reassembly shop.
2) A shop of this class is manned by a substantial number of mechanics whose interchangeable skills make it possible to work on a variety of jobs in backlog.
3) Jobs in these shops have individual work content which

is small relative to the total load in the shop. Since work content is small it is also generally true that a single worker at a time processes each job.

4) Shops in this class are not highly dependent on equipment capacity as limiters.

From a production control viewpoint, the shop is composed of three basic elements: the workable backlog area, the nonworkable backlog area, and the processing area (see Figure 1). Jobs arrive at the shop and normally are entered into the workable backlog, to await processing by an available worker. If, for some reason, a job cannot be processed "as is," it is entered into the nonworkable backlog. Usually jobs will be placed in the nonworkable backlog because fo the nonavailability of a component part required for processing or technical data required for processing. Once the nonavailability is satisfied, the job returns to the workable backlog.

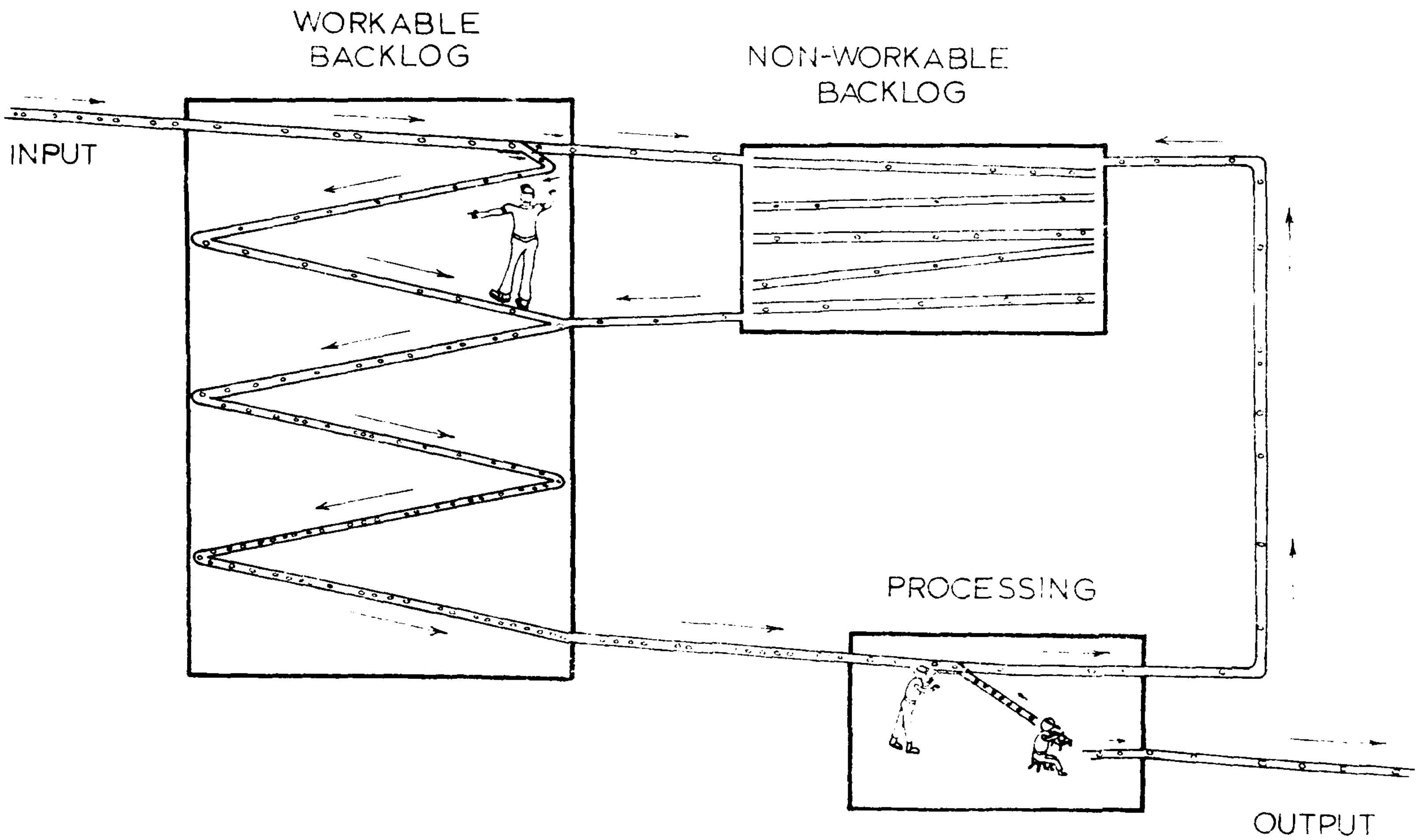
Jobs move from the workable backlog to the processing area as needed. Sometimes, during the initial disassembly of a job, it is determined that an additional component part(s) will be necessary to complete the job. If the component part(s) is not available, the job is entered into the nonworkable backlog (see Figure 1). When processing is completed on a job, it leaves the shop.

Management has at least two methods by which they can exercise control over the shop on a week to week basis. First, they can increase the shop capacity by moving qualified workers into the shop from other shops in the NARF, or they can decrease the shop capacity in the same manner. Second, they can increase shop capacity by working the existing shop manpower overtime. Management control of the shop is exercised with the objective of performing the mission of the shop, and incurring the least possible cost. Clearly, these two objectives are somewhat in conflict. Consequently, any rational control policy is formed by trading of mission performance with cost of operation.

The use of overtime increases the operating cost of the system. In addition to an increased labor rate, overtime work usually is performed at a lower effidiency rate than that of straight time work. It would seem initially that increasing the shop capacity by bringing in more workers would be preferable to overtime, but that also results temporarily in increased costs caused primarily by two factors. First, there is an administrative cost for moving workers. Second, and more important, workers moved into a shop take time to learn their jobs and, consequently, work at a reduced rate for a period immediately after assignment to the shop (assuming that the worker is qualified, this period of lowered efficiency may last one to three weeks).

The amount of work in the system is of concern to management. Low backlog levels may cause inefficient manpower utilization. If the workable backlog is depleted, the workers in the shop will be idle. Another possibility is that if the workable backlog nears depletion, the workers' efficiency will decrease, thereby resulting in an application of Parkinson's Law. In any event the effect on the system is the same. Its efficiency is reduced.

If backlogs are too large, management also has reason for concern. Large backlogs result in increased flow time for jobs




SCHEMATIC OF THE SHOP

FIGURE 1

in the system. If a job has come from an aircraft being reworked at the NARF, an excessive delay of the job in the shop will cause the processing of an aircraft to be delayed. This will result in a real cost for NARF. If a job is for the Navy supply system, an excessive delay of the job will cause a depletion of the Navy inventory which may result in the grounding of a fleet aircraft. In either case, the result is a reduction of the number of operational aircraft available to the Navy.

The shop model program was written to provide a high feedback environment for training production control personnel. Use of the model should allow beginning personnel to get a better understanding of the dynamics of the shop.

## III. PROGRAM STRUCTURE

In order to discuss the internal structure of the shop model program it is first necessary to describe the different paths that a job can take through the shop.

1) The job enters the shop and is placed on the workable backlog. It is then worked on, completed, and leaves the shop.
2) The job enters the shop and is placed on the nonworkable backlog for some non-availability. Later when the non-availability is satisfied the job is placed on the workable backlog. It is then worked on, completed, and leaves the shop.
3) The job enters the shop and is placed on the workable backlog. It is then worked on but not completed due to lack of parts or skills. The job is plaed on the nonworkable backlog until the parts or skills are available, when it is placed back on the workable backlog. The job is then completed and leaves the shop.
4) The job enters the shop and is placed on the nonworkable backlog. After the necessary conditions have been satisfied it is placed on the workable backlog. It is then worked on but not completed due to lack of parts or skills. The job is placed on the nonworkable backlog. Later the job is put back on the workable backlog, worked on, completed, and leaves the shop.

These paths can be seen in the shop schematic in figure 1. For simplicity any further reference to the different paths will be by the numbers given above.

Examination of these paths reveal many similarities. This makes it possible to write the program so that the jobs are grouped together on the backlogs regardless of the route they are on.

The program stores the backlogs, event list, and the workers all on a single linked list. This requires the storage of the [illegible] If the user wishes to input the information directly the program calls subroutine INPUT. Optionally the program calls subroutine DATA to input the information from a stored data file. In either case the program must then call subroutine PARAM. This subroutine calculates the two needed parameters of the nonworkable delay time distribution from the given mean and standard deviation.

The program achieves steady state conditions by running the

model for twenty weeks( pg. 2B ). These weeks use a target value determined by the number of men in the shop at the start of the simulation. After the shop has been initialized the program outputs the current shop status ( See Appendix C ), and prompts the user for information required for the upcoming week. The information required is the induction target value, amount of overtime, and the number of workers transferring in or out of the shop. The workers' efficiency ratings are then updated for the upcoming week. After adding or deleting workers the program is ready to simulate the week.

Jobs are generated and given exponentially distributed job sizes ( pg. 4B ). A certain percentage of these jobs are then placed on the nonworkable backlog and the rest on the workable backlog. When a job is placed on the nonworkable backlog the program calls subroutine DELAY to calculate the delay time. The delay time distribution is a two-stage general erlang distribution. The subroutine computes the delay time so that the job's event time is not during the night. When a job is placed on the workable backlog the program calculates ten percent of the job size and stores this value. This enables the program to check the job after ten percent has been completed. This process continues until the total amount of work generated exceeds the target value.

The program places an event on the event list to mark the end of the regular work day. Idle workers are given jobs to number on which the first and last entries of each seperate list are located. Each entry must include the row number of the next entry on the list. The linked list is composed of six seperate vectors. The information stored in the vectors varies depending upon the particular list and path the job is on. For a complete description of the information stored in the vectors see pg. 2A

Every operation performed by the model requires an entry be taken off a list and then placed back on a list. This is achieved by subroutines TAKE and PUT respectively. Each of these subroutines Entries are always taken off the front of a list. The subroutine must be passed the location of the first and last entry on the list. Subroutine TAKE sets a flag when the last entry of a list has been removed. An entry may be placed on the front, back, or middle of a list. Entries placed in the middle of a list go directly in front of the entry with a greater value in vector EVENT. Subroutine PUT also requires the location of first and last entries of the list. Additionally the subroutine needs the method of entry placement. Both subroutines use an integer vector and two real variables to transfer the information to the main program.

With these two tools and others which will be discussed when needed, it is possible to begin the discussion of how the program operates. All references in this section refer to the logic flow diagram in Appendix B. The program first obtains the values of the various shop parameters, initializes the linked list, sets pointers, and then runs the shop to reach steady state conditions ( pg. 1B ). From this point the simulation proceeds one week at a time, asking for weekly information and outputting the week's results. After the simulation is over it then calculates and outputs the final status of the shop.

Three subroutines are used to input the required shop parameters. If the user wishes to input the information directly

the program calls subroutine INPUT. Optionally the program calls subroutine DATA to input the information from a stored data file. In either case the program must then call subroutine PARAM. This subroutine calculates the needed parameters of the nonworkable delay time distribution from the given mean and standard deviation.

The model is then operated for twenty weeks to bring the shop to steady state conditions ( pg. 2A ). After the shop has been initialized the current shop status is outputted ( See Appendix C ). The program then prompts for the information required to simulate the upcoming week. The information required is the induction target value, amount of overtime, and number of workers transferring in or out of the shop. The efficiency rating of each worker is updated by one week. Transfer of workers in or out of the shop occurs at this point ( pg. 3B ).

Jobs are generated and given an exponentially distributed job size ( pg. 3B ). A certain percentage of these jobs are then placed on the nonworkable backlog and the rest are placed on the workable backlog. When a job is placed on the nonworkable backlog the program calls subroutine DELAY to compute the delay time. The delay time distribution is a two-stage erlang distribution. This delay time is added to the current clock value and adjusted so that the move time is not when the shop is closed for the night. When jobs are placed on the workable backlog the program computes ten percent of the job size and stores this value with the entry. Jobs are generated until the total amount of work generated exceeds the inputted target value.

The program begins the simulation by placing an entry on the event list to indicate the end of the day. Next the workers that are idle are given jobs from the workable backlog. Move time for these jobs are determined by adding the current clock value to the appropriate amount of the job size. This value is either ten percent or 90 percent depending on whether the job has been in process before (i.e. job is on paths 3 or 4). The workers efficiency rating is used to adjust the move time to reflect the additional time needed by adjusting workers. When a worker takes a job his idle time is computed by subroutine [illegible]. This continues until either no workers are idle or no jobs remain on the workable backlog.

Simulation proceeds by setting the clock equal to the move time of the first entry on the event list. This entry is removed and the program checks to see what the next operation is ( pg. 5B ). If the job is completed then the program must update the appropriate statistics and counters. Then subroutine NEWJOB is called to give the freed worker another job if one is available. When no jobs are available the worker is flagged idle until one becomes available. Otherwise the job is either going from the nonworkable to the workable backlogs or in process with ten percent completed. In the first case the job is placed on the workable backlog directly if already in process before, and if not then the ten percent value of the job size is determined and stored with the entry on the workable backlog. In the second case the program will send the job to the nonworkable backlog a given percentage of the time, while the rest continue to be worked on until completion. The last

possibility is that the end of day indicator is taken off the event list. Until this occurs the program loops back and takes the next event off the event list.

When the end of the day indicator is taken off the event list the program must do several things ( pg 6B ). The first thing is to put the end of day indicator for the next day onto the event list. After doing this the program then determines whether or not workers are to use overtime and how much. If no overtime is available the move times of jobs being worked on are adjusted to occur during the next day. This requires that the job first be found ( It is not necessarily the first entry on the event list ) and then placed back on with the adjusted move time. Subroutine RESORT is used to perform both of these operations. If overtime is available the the job is either worked on for the overtime interval and then adjusted, or completed freeing the worker. When a job is completed during overtime it is treated exactly as before and the worker is given a new job if it is available. If the worker receives a new job during the overtime period its move time is immediately adjusted to the next day. This means that a worker can not complete more than one job in any single overtime period. After all the workers have been dealt with the program starts another day. This continues until five days or a week have been completed.

When a full work week has been simulated the program outputs the contents of the backlogs. Included in this output are the worker idle time, work completed, average flow time, and number of workers in the shop ( pg. 7B ). This information with the exception of the average flow time is updated continuously and is available at any time. The average flow time is computed at the end of the week. The output is generated by subroutine OUTPUT. The program will then ask if another week is to be simulated.

When no more weeks are to be simulated the program computes the average and standard deviation of the flow time through the shop. Subroutine FINAL is then called and this information along with the total idle time, jobs completed, and hours completed are outputted. The subroutine also computes the shop efficiency and outputs it too. Program execution is then terminated.

APPENDIX A

Shop Schematic and
Memory Storage

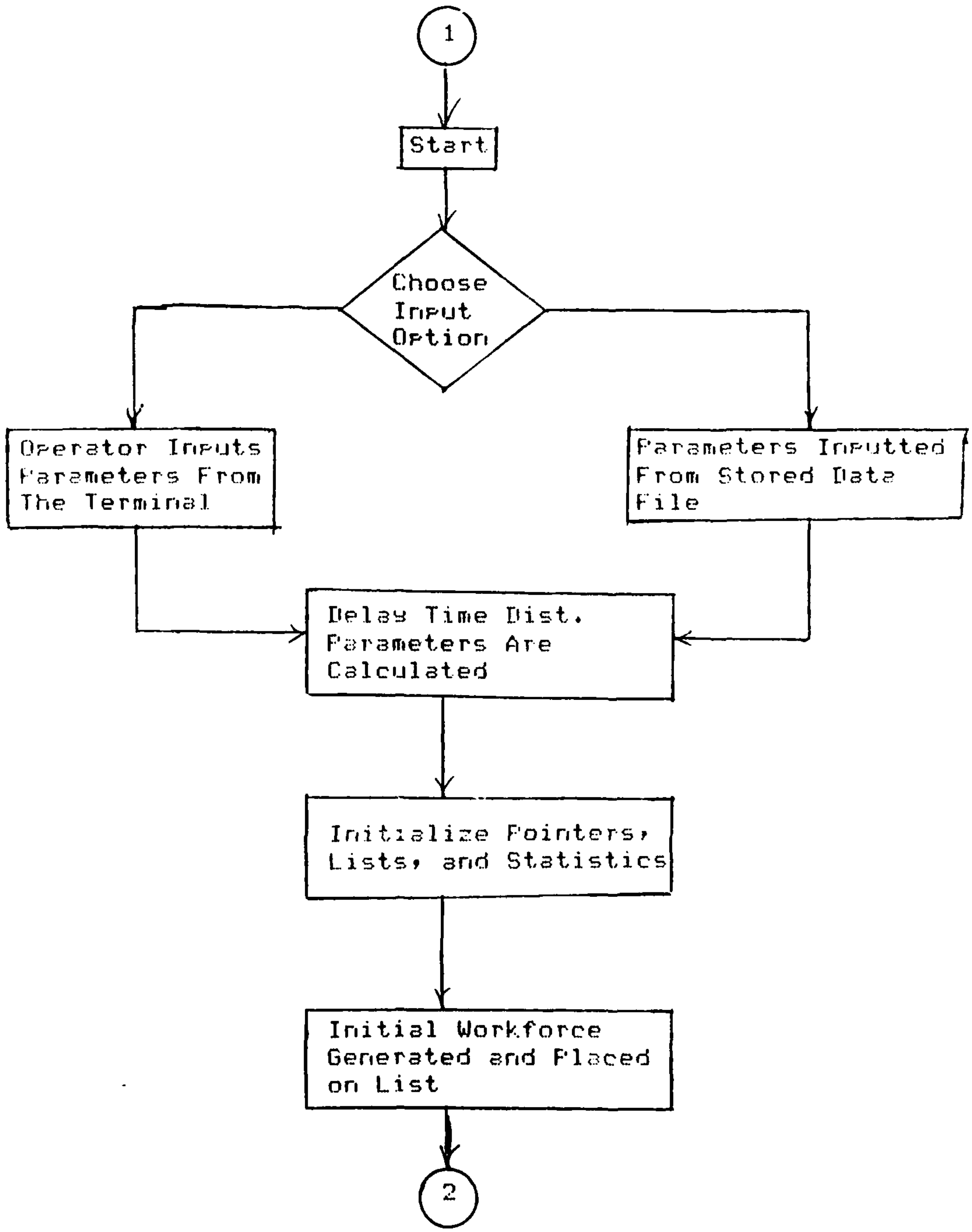
| Vector | Contents for entry on workable backlog |
|---|---|
| EVENT | Ten percent of the job size |
| FLOW | Value of clock when job was generated |
| JOBSIZ | Job size |
| REMAIN | Ninety percent of job size |
| DIRECT | Row of next entry on Workable backlog |
| WORK | 0 if not being worked on and the worker # if it is |

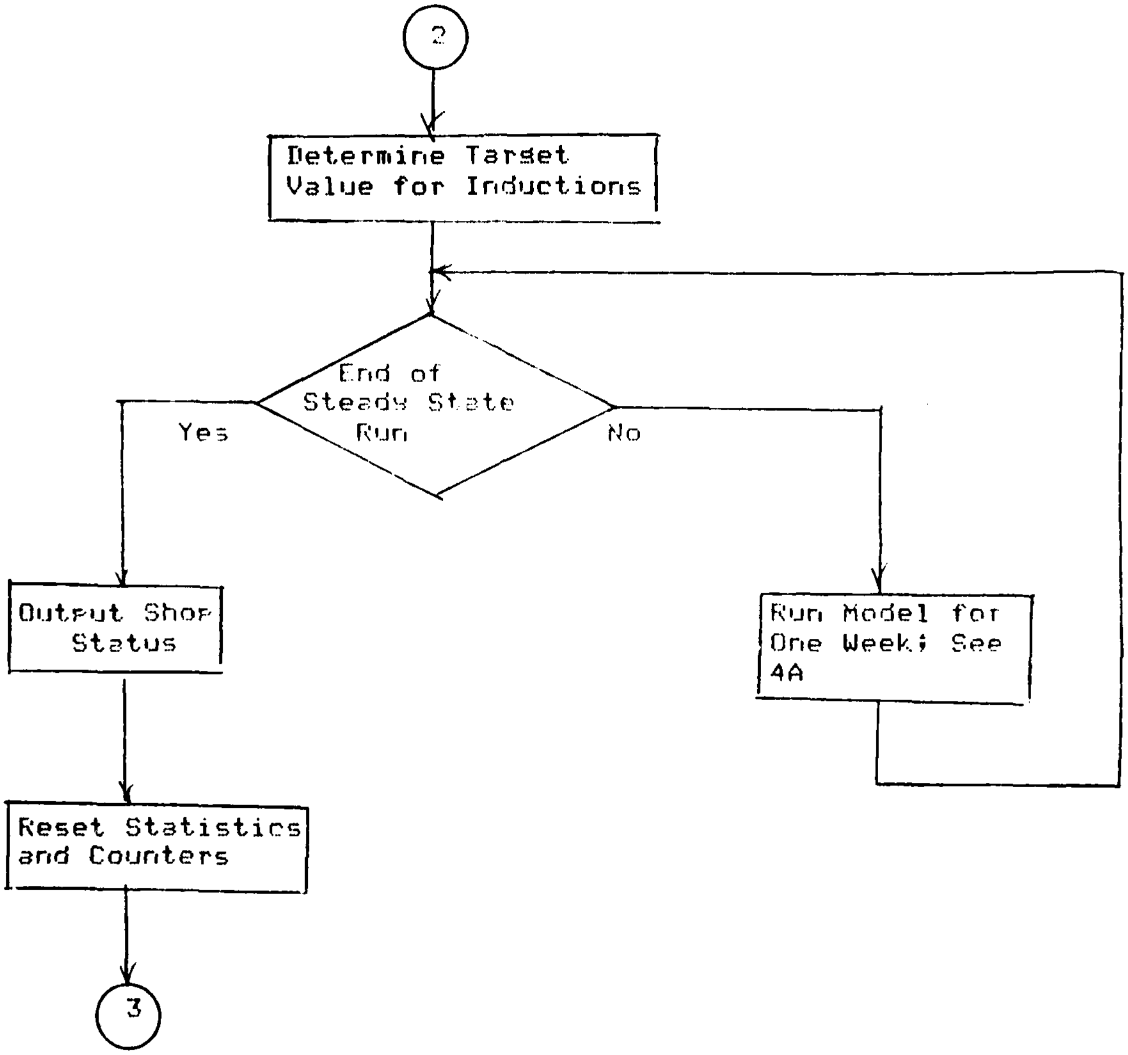
| Vector | Contents for entry on Nonworkable backlog |
| --- | --- |
| EVENT | Time until job moves in model |
| FLOW | Value of clock when job was generated |
| JOBSIZ | Job size |
| REMAIN | ----------------- |
| DIRECT | Row of next entry on Nonworkable backlog |
| WORK | -2 if from in process<br>-1 if never in process |

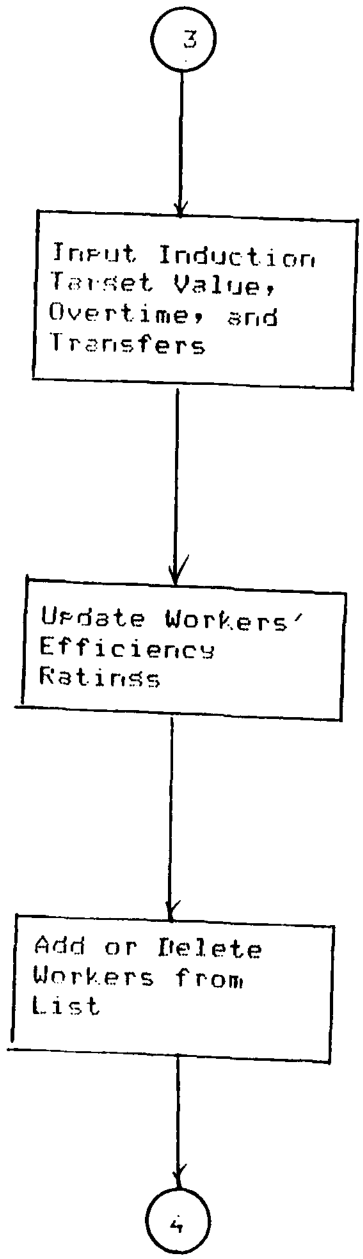
| Vector | Contents for entry on Worker list |
|---|---|
| EVENT | Efficiency rating for current week |
| FLOW | ---------------------- |
| JOBSIZ | Number of weeks worker has been in the shop |
| REMAIN | -1 |
| DIRECT | Row of next entry on Worker list |
| WORK | ------------------ |

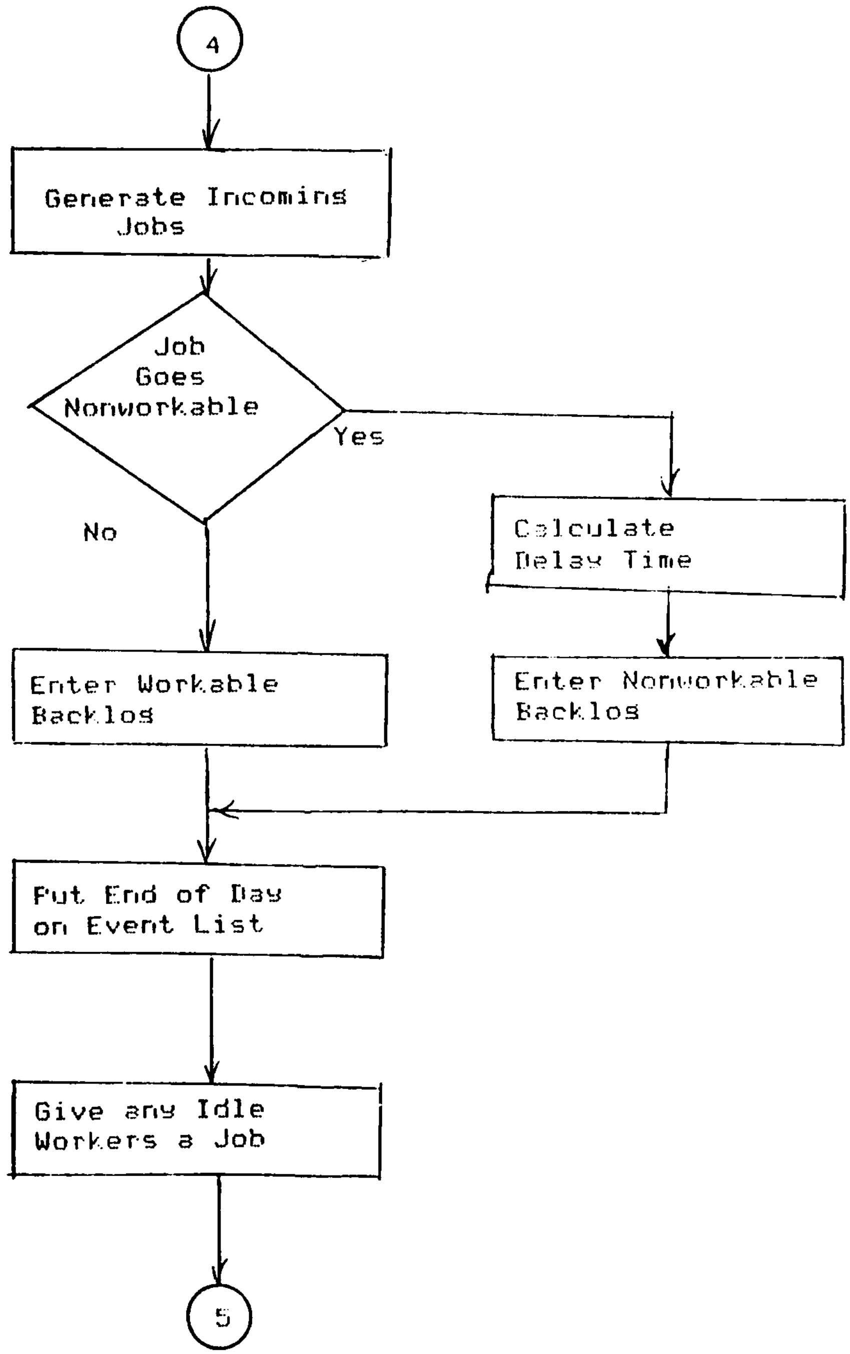
APPENDIX B

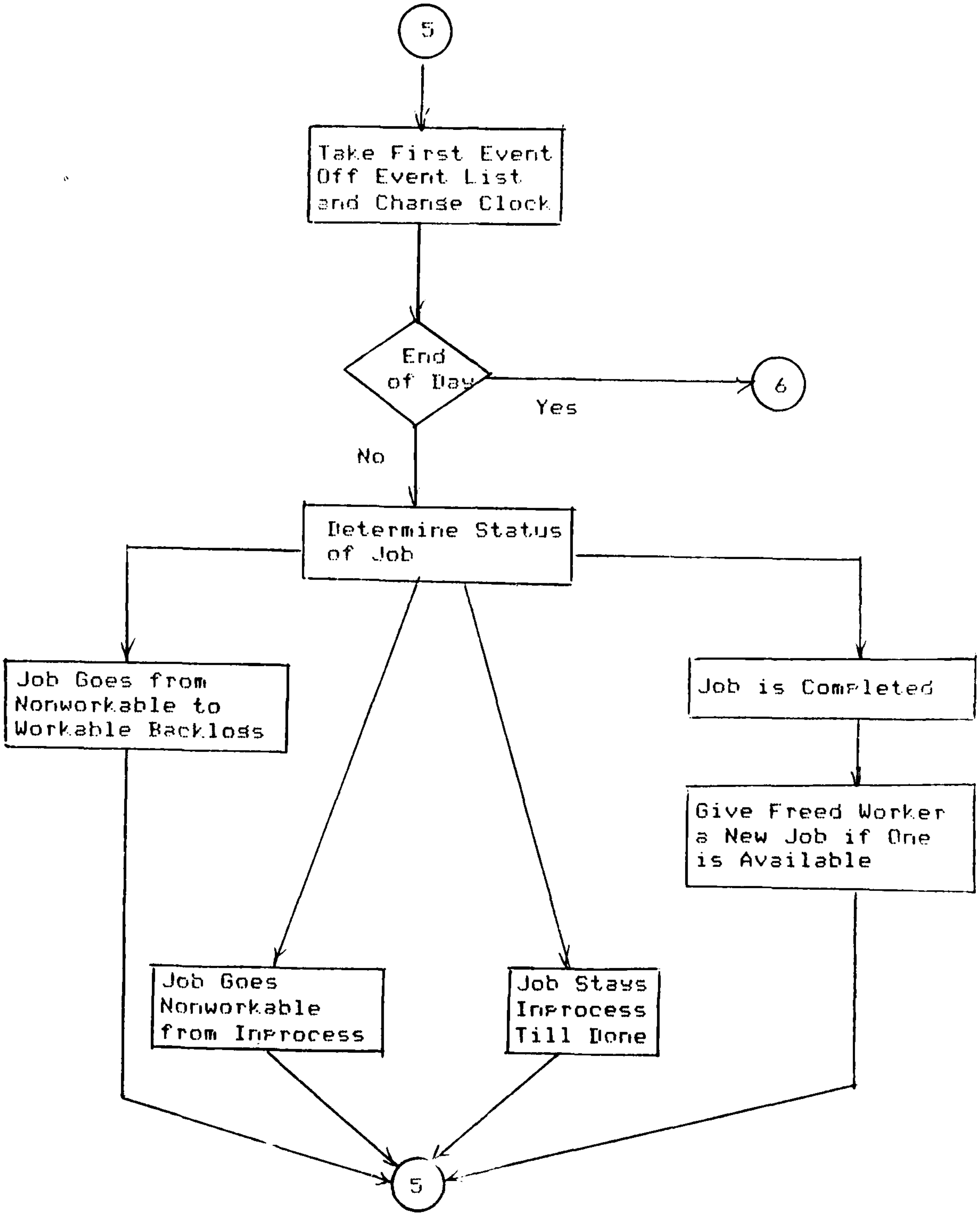
Flow Diagram

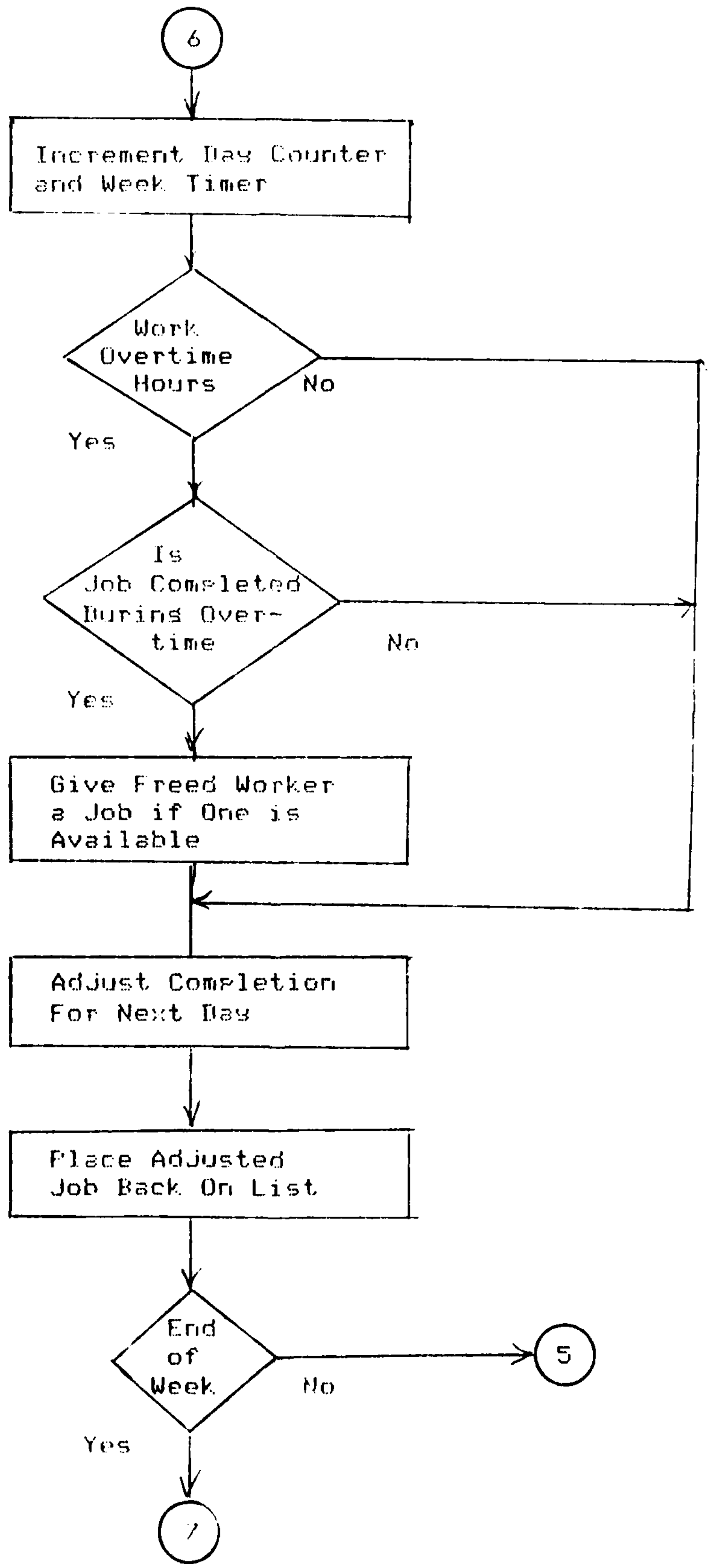

1
Start
Choose Input Option
Operator Inputs Parameters From The Terminal
Parameters Inputted From Stored Data File
Delay Time Dist. Parameters Are Calculated
Initialize Pointers, Lists, and Statistics
Initial Workforce Generated and Placed on List
2

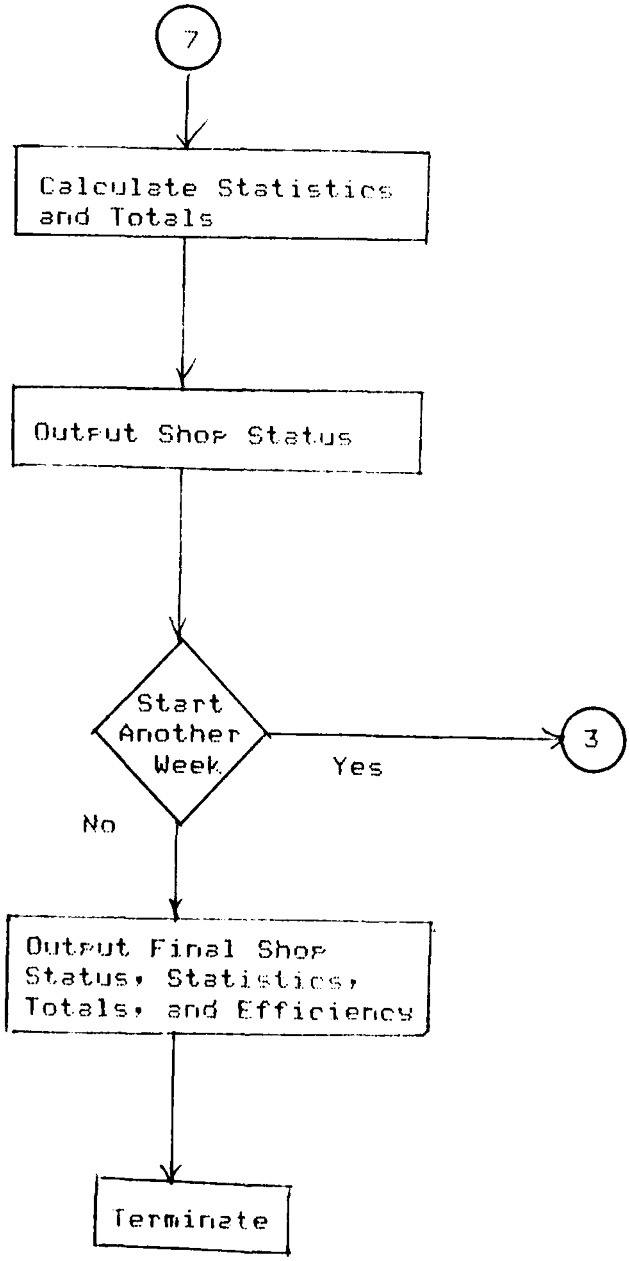

2
Determine Target Value for Inductions
End of Steady State Run
Yes
No
Output Shop Status
Run Model for One Week; See 4A
Reset Statistics and Counters
3


3
Input Induction Target Value, Overtime, and Transfers
Update Workers' Efficiency Ratings
Add or Delete Workers from List
4


4
Generate Incoming Jobs
Job Goes Nonworkable
Yes
No
Calculate Delay Time
Enter Workable Backlog
Enter Nonworkable Backlog
Put End of Day on Event List
Give any Idle Workers a Job
5


5
Take First Event Off Event List and Change Clock
End of Day
Yes
6
No
Determine Status of Job
Job Goes from Nonworkable to Workable Backlogs
Job Goes Nonworkable from Inprocess
Job Stays Inprocess Till Done
Job is Completed
Give Freed Worker a New Job if One is Available
5


6
Increment Day Counter and Week Timer
Work Overtime Hours
No
Yes
Is Job Completed During Over-time
No
Yes
Give Freed Worker a Job if One is Available
Adjust Completion For Next Day
Place Adjusted Job Back On List
End of Week
No
5
Yes
7


7
Calculate Statistics and Totals
Output Shop Status
Start Another Week
Yes
3
No
Output Final Shop Status, Statistics, Totals, and Efficiency
Terminate

# APPENDIX C

## Users' Manual

The shop training program was written for use in training production control personnel. The main objective is to give the user a feel for how the shop operates. It is possible to see the effects of various scheduling decisions on the shop. Program SHOP was intended as a learning tool and should be treated as such.

The shop is composed of three basic elements: the workable backlog area, the nonworkable backlog area, and the processing area (see fig. 1A). Jobs arrive at the shop and normally are entered into the workable backlog, to await processing by an available worker. If, for some reason, a job cannot be processed "as is," it is entered into the nonworkable backlog. Usually jobs will be placed in the nonworkable backlog because of the nonavailability of a part or technical data required for processing. Once the nonavailability is satisfied, the job returns to the workable backlog.

Jobs move from the workable backlog to the processing area as needed. Sometimes, during the initial disassembly of a job, it is determined that an additional part(s) is needed to complete the job. If the part(s) is not available, the job is entered into the nonworkable backlog (see Figure 1). When processing is completed on a job, it leaves the shop.

This manual is a step by step discription for operating the program "SHOP". The program is a simulation model of a typical N.A.R.F. shop. To run the program type in "RUN SHOP". In the following text program instructions and displays are identified by (PROG). Input to the program is required when you see (USER).

At the beginning of the program you must choose an option for entering the initial parameters.

(PROG) DO YOU WISH TO INPUT PARAMETERS YOURSELF? [Y/N]

(USER) If you enter "N" the the parameters will be read from a stored data file.

If you choose to input the parameters yourself then the program will prompt for the information as seen in the next section. If you choose to read the values from a stored file then skip to the section after the second line of asteriks(****).

***********************************************************************

(PROG) INPUT PROBABILITY JOB IS DETERMINED NON-WORKABLE UPON ENTERING SHOP.

(USER) Enter the probability as a decimal number between 0.0 and 1.0.

(PROG) INPUT PROBABILITY JOB GOES NON-WORKABLE AFTER START OF PROCESSING.

(USER) Same as above.

(PROG) INPUT MEAN DELAY TIME IN DAYS.

(USER) Number must include decimal point.

(PROG) INPUT STANDARD DEVIATION OF DELAY TIME.

(USER) Same as above.

(PROG) INPUT INTEGER (ODD) SEED FOR RANDOM NUMBER GENERATOR.

(USER) Seed must be an odd integer between -99 and 999.

(PROG) INPUT AVERAGE JOB SIZE IN STANDARD MAN-HOURS.

(USER) Enter number.

(PROG) INPUT NUMBER OF WEEKS UNTIL TRANSFERED PERSONNEL ADJUSTED AND WORKING FULL EFFICIENCY.

(USER) If worker is at full efficiency during third week then enter a "3".

(PROG) INPUT EFFICIENCY RATING OF TRANSFERED WORKER FOR FIRST WEEK IN SHOP.

(USER) If the worker is expected to work at 80% efficiency then enter "0.8".

(PROG) INPUT EFFICIENCY RATING FOR NEXT WEEK.

(USER) The program will ask for efficiency ratings for all but the last week of the adjustment period. The program sumes that the last week in the period is done at full efficiency, so it assigns a rating of 1.0.

*****************************************************************

(PROG) INPUT NUMBER OF WORKERS IN SHOP AT START OF SIMULATION.

(USER) Enter number.

Any error in the input data will result in the question being repeated. If you choose to read the parameters from the data file, the program will still prompt you for the number of men in the shop.

After the parameters are entered the program initializes the shop. This is accomplished by operating the shop for twenty weeks.

(PROG) MODEL BEING INITIALIZED

The initialization process causes a short delay after which the program displays information on the backlogs. The information is displayed in the following format.

(PROG) RESULTS FOR WEEK 0

| BACKLOG | NO. OF JOBS | NO. OF HOURS OF WORK |
|---|---|---|
| WORKABLE | XXXX | XXXX.X |
| NON-WORKABLE | XXXX | XXXX.X |

WORKERS WERE IDLE XXX.X HOURS.

WORK COMPLETED THIS WEEK TOTALLED XXX.X HOURS.

AVERAGE FLOW TIME XXX.X DAYS.

NUMBER OF WORKERS IN SHOP IS XXX.

The program will then prompt you for the information on the upcoming week.

(PROG) SUPPLY INDUCTIONS TO SHOP FOR UPCOMING WEEK.

(USER) Enter the target value for the week in hours.

(PROG) INPUT OVERTIME HOURS AVAILABLE THIS WEEK.

(USER) Enter the total amount of overtime hours available.

(PROG) INPUT NUMBER WORKERS TRANSFERRING TO/FROM SHOP.

(USER) Enter a positive number if transferring into the shop, and a negative number if leaving shop.

The program will then display the results for the week in the same format as above, and ask if you wish to continue.

(PROG) DO YOU WISH TO OPERATE ANOTHER WEEK? [Y/N]

(USER) Entering a "N" results in output of final statistics and termination of program.

Final results of the simulation are outputted in the following format.

(PROG)            FINAL RESULTS FOR XX WEEKS

XXX JOBS WERE COMPLETED TOTALLING XXX.X HOURS OF WORK.

AVERAGE FLOW TIME WAS XX.X DAYS WITH A
STANDARD DEVIATION OF XX.X

WORKERS WERE IDLE FOR XXX.X HOURS

SHOP OPERATED AT XX.X %

There are two conditions which will cause the program to terminated prematurely.

(1) Number of jobs in shop exceeds the maximum number of jobs allowed.

(2) Last worker in shop is transferred out.

It should be noted at this point that the major factor affecting the overall operation of the shop is the status of the workable backlog. Operation of the model for a period of weeks should show that worker idle time increases when the content of this backlog is low. Any increase in idle time will lower the efficiency of the shop. At the same time it is important that the workable backlog does not become to full. This would result in a larger non-workable backlog which in turn increases the storage space needed.

APPENDIX D

Program Code

```
C*******************   ***********   ********************************
C**   PROGRAMMED BY: JOHN C GILMOUR                                   **
C**                  THOM J HODGSON                                   **
C**                  INDUSTRIAL AND SYSTEMS ENGINEERING DEPT.         **
C**                  UNIVERSITY OF FLORIDA                            **
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C**                  TELEPHONE (904)392-1464                          **
C*********************************************************************
C**   THE FOLLOWING PROGRAM IS A SIMULATION MODEL FOR A TYPICAL       **
C**   N.A.R.F. SHOP.  JOBS ARE SCHEDULED BY STANDARD MANHOUR          **
C**   CONTENT.  THE FOLLOWING IS  LIST OF THE MAJOR VARIABLES         **
C**   AND THEIR DEFINITIONS.                                          **
C**     P1 = PROBABILITY JOB WILL GO NON-WORKABLE UPON ENTRY TO       **
C**          SHOP.                                                    **
C**     P2 = PROBABILITY JOB WILL GO NON-WORKABLE AFTER PROCESS-      **
C**          ING HAS BEGUN.                                           **
C**     LAM1 & LAM2 = PARAMETERS FOR DELAY TIME DISTRIBUTION.         **
C**     MNJOB = AVERAGE JOBSIZE IN MANHOURS.                          **
C**     DMEAN = MEAN DELAY TIME.                                      **
C**     DSTDEV = STANDARD DEVIATION OF DELAY TIME.                    **
C**     NWK = NUMBER OF WEEKS UNTIL TRANSFERED PERSONNEL ARE          **
C**           FULLY ADJUSTED.                                         **
C**     NORMEN = NO. OF REGULAR WORKERS IN SHOP.                      **
C**     ADDMEN = NO. OF WORKERS TO BE TRANSFERED IN OR OUT            **
C**     OVRTM = HOURS OF OVER TIME AVAILABLE FOR WEEK.                **
C**     HOUR = TARGET VALUE FOR SCHEDULING JOBS FOR WEEK.             **
C**     EMPTY = ROW NO. OF FIRST EMPTY ENTRY.                         **
C**     WQF = FIRST ENTRY IN WORKABLE QUEUE.                          **
C**     WQL = LAST    "    "     "      "  .                          **
C**     NWQF = FIRST ENTRY IN NON-WORKABLE QUEUE.                     **
C**     NWQL = LAST    "    "     "       "   .                       **
C**     WRKF = FIRST ENTRY IN WORKER LIST.                            **
C**     WRKL = LAST    "    "    "    "  .                            **
C**     I1 & I2 = SEEDS FOR UNIFORM RANDOM NUMBER GENFRATOR.          **
C**     CLOCK = TIME SINCE SIMULATION STARTED.                        **
C**     TIMER =    "     "   WEEK STARTED.                            **
C**     MAXLST = MAXIMUM NUMBER OF ENTRIES IN LIST                    **
C**   FOR EACH J                                                      **
C**     JOBSIZ(J) = JOBSIZE IN MANHOURS FOR A JOB OR EFFIECENCY       **
C**                 RATING IF A WORKER.                               **
C**     EVENT(J) = TIME TILL JOB MOVES IN MODEL.                      **
C**     REMAIN(J) = TIME REMAINING IN JOB.                            **
C**     DIRECT(J) = NEXT MEMBER IN LIST AFTER MEMBER J                **
C**     WORK(J) = STORES WORKER NO. AND OTHER FLAGS.                  **
C**     FLOW(J) = TIME JOB ENTERED SHOP.                              **
C**     JOB(J) = DIFFERENT ELEMENTS OF ENTRY TO LIST.                 **
C**     EFF(J) = EFFICIECNY OF WORKER IN WEEK J AFTER TRANSFER.       **
C**   OTHER VARIABLES ARE USED IN VARIOUS SECTIONS OF THE PROGRAM     **
C*********************************************************************
      IMPLICIT INTEGER*2(B-O,S-Z)
      INTEGER REMAIN,ADDMEN
      REAL*8 AVFLOW,SDFLOW
      REAL EVENT,P1,P2,MNJOB,LAM1,LAM2,CLOCK,TIME,EFF(6),IDLTM,
     *     HRWK,HRNWK,HRDONE,THRDNE,CHRDNE,TOTIDL,FLOW,
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      *     TOTFLO,PREFLO,SQFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
      *           DIRECT(1000),WORK(1000),JOB(3)
      LOGICAL*1 ANS,REPLY,YES,NO
      DATA YES/'Y'/,NO/'N'/,MAXLST/1000/
      CALL ASSIGN(6,'TI:')
      CALL ASSIGN(3,'DATA.DAT')
C*********************************************************************
C**                 INPUT PARAMETERS AND CONSTRAINTS               **
C*********************************************************************
      TYPE 4
4     FORMAT(10(/),20X,25('*')/20X,'*  N.A.R.F. SHOP MODEL  *'/20X,
      *           25('*')//
      *           '0   THIS PROGRAM IS A COMPUTER MODEL OF A TYPICAL'/
      *           ' N.A.R.F. SHOP.  TO INITIALIZE  MODEL CERTAIN'/
      *           ' PARAMETERS ARE NEEDED.  THE PROGRAM ALLOWS DIRECT'/
      *           ' INPUT OF  PARAMETERS OR READS FROM A STORED'/
      *           ' DATA FILE 'DATA.DAT'.  TO USE THE PROGRAM'/
      *           ' INPUT THE INFORMATION PROMPTED FOR.  THE FOLLOWING'/
      *           ' INFORMATION IS PROVIDED EACH WEEK: CONTENTS OF '/
      *           ' BACKLOGS, HOURS WORK COMPLETED, HOURS IDLE, AND'/
      *           ' AVERAGE FLOW TIME.  FINAL RESULTS SHOW HOURS WORK'/
      *           ' COMPLETED, HOURS IDLE, AVERAGE FLOW TIME, STANDARD'/
      *           ' DEVIATION OF FLOW TIME, AND SHOP EFFICIENCY.'/)
30    TYPE 6
6     FORMAT(/' WANT TO INPUT PARAMETERS YOURSELF? [Y/N] ',$)
      READ (6,35,ERR=30) ANS
35    FORMAT(A1)
      IF(ANS.NE.YES) GO TO 40
      CALL INPUT(P1,P2,I1,I2,DMEAN,DSTDEV,NWK,MNJOB,NORMEN,EFF)
      GO TO 45
40    IF(ANS.NE.NO) GO TO 30
      CALL DATA (P1,P2,I1,I2,DMEAN,DSTDEV,NWK,MNJOB,NORMEN,EFF)
45    CALL PARAM(DMEAN,DSTDEV,LAM1,LAM2)
      TYPE 46
46    FORMAT(10(/),'  MODEL BEING INITIALIZED',10(/))
C*********************************************************************
C**                   INITIAL LIST IS EMPTY                        **
C*********************************************************************
      MXLST1 = MAXLST-1
      DO 50 M=1,MXLST1
50    DIRECT(M) = M+1
      DIRECT(MAXLST) = 0
C*********************************************************************
C**                 INITIALIZE POINTERS                            **
C*********************************************************************
      FLAG = 1
      IDLE = 0
      NOJOB = 1
      NWQF = 0
      NWQL = 0
      WQF = 0
      WQL = 0
      WRKL = 0
```

```
      WRKF = 0
      EMPTY = 1
      WEEK = 0
      JOBWK = 0
      HRWK = 0.0
      JOBNWK = 0
      HRNWK = 0.0
      CLOCK = 0.0
      HRDONE = 0.0
      THRDNE = 0.0
      TOTFLO = 0.0
      SQFLOW = 0.0
      SUM = NORMEN
      ITR = NORMEN
C*****************************************************************************
C**                  GENERATE WORKERS                                       **
C*****************************************************************************
      DO 60 K=1,NORMEN
      JOB(1) = NWK
      TIME = 1.0
      JOB(2) = -1
      JOB(3) = 0
      PNT = EMPTY
      CALL PUT(WRKF,WRKL,0,TIME,RFLOW,EMPTY)
60    CONTINUE
      HOURS = NORMEN*400
      OVRTM = 0
      ADDMEN = 0
90    IF(WEEK.EQ.20) FLAG = 0
      WEEK = WEEK+1
      IF(FLAG.EQ.1) GO TO 200
      WEEK = 0
      CALL OUTPUT(JOBWK,HRWK,JOBNWK,HRNWK,CHRDNE,WEEK,SUM,
     *             IDLTM,AVFLOW)
      RHOUR = HRDONE
      JCOMP = 0
      JBWK = 0
      TOTIDL = 0.0
      RDFLOW = TOTFLO
      RSQFLO = SQFLOW
C*****************************************************************************
C**                  INPUT DATA FOR UPCOMING WEEK                           **
C*****************************************************************************
100   WEEK = WEEK+1
      IDLTM = 0.0
115   TYPE 116
116   FORMAT(/' SUPPLY INDUCTIONS TO SHOP FOR NEXT WEEK (HOURS) ',$)
      READ(6,117,ERR=115) HOURS
117   FORMAT(I5)
      HOURS = HOURS*10
120   TYPE 121
121   FORMAT(/' INPUT OVERTIME HOURS AVAILABLE THIS WEEK. ',$)
      READ(6,117,ERR=120) OVRTM
125   TYPE 126
```

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 117  FORMAT('0INPUT NUMBER WORKERS TRANSFERRING TO/FROM SHOP. ENTER
     *          ' POSITIVE NUMBER IF TRANSFERRING INTO SHOP, AND
     *          ' NEGATIVE NUMBER IF LEAVING SHOP.',$)
      READ(5,117,ERR=125) ADDMEN
C**********************************************************************
C**              UPDATE WORKER STATUS                                **
C**********************************************************************
 140  PNT = WRKF
 150  IF(JOBSIZ(PNT).EQ.NWK) GO TO 160
      JOBSIZ(PNT) = JOBSIZ(PNT)+1
      EVENT(PNT) = EFF(JOBSIZ(PNT))
 160  PNT = DIRECT(PNT)
      IF(PNT.NE.0) GO TO 150
C**********************************************************************
C**              ADD OR DELETE WORKERS                               **
C**********************************************************************
      SUM = SUM+ADDMEN
      IF(ADDMEN.EQ.0) GO TO 200
      IF(ADDMEN.LT.0) GO TO 175
      DO 170 K=1,ADDMEN
      JOB(1) = 1
      TIME = EFF(1)
      JOB(2) = -1
      JOB(3) = 0
      IDLE = IDLE+1
      PNT = EMPTY
      CALL PUT(WRKF,WRKL,0,TIME,RFLOW,EMPTY)
      CALL TIDLE(SUM,CLOCK,0,PNT,IDLTM,ITR,TOTIDL)
      CALL NEWJOB(PNT,WQF,WQL,NWQF,NWQL,EMPTY,JOBWK,HRWK,
     *            CLOCK,NOJOB,IDLE,SUM,IDLTM,ITR,TOTIDL)
 170  CONTINUE
      GO TO 200
C**********************************************************************
C**                   DELETE WORKERS                                 **
C**********************************************************************
 175  ADDMEN = -ADDMEN
      DO 180 K=1,ADDMEN
      CALL DELETE(WQF,WQL,NWQF,NWQL,WRKF,WRKL,EMPTY,CLOCK,IDLE,
     *            JOBWK,HRWK)
 180  CONTINUE
C**********************************************************************
C**                   GENERATE INCOMING JOBS                         **
C**********************************************************************
 200  THOURS = 0
      IF(HOURS.EQ.0) GO TO 240
 210  MAXJOB = JOBWK+JOBNWK+SUM+1
      IF(MAXJOB.GE.MAXLST) GO TO 810
      JOB(1) = -ALOG(RAN(I1,I2))*MNJOB*10
      IF(JOB(1).EQ.0) GO TO 210
      RFLOW = CLOCK
      IF(RAN(I1,I2).GT.P1) GO TO 220
C**********************************************************************
C**                   ENTER NON-WORKABLE QUEUE                       **
C**********************************************************************
```

```
      JOB(3) = 1
      JOBNWK = JOBNWK+1
      HRNWK = HRNWK+JOB(1)
      CALL DELAY(TIME,I1,I2,LAM1,LAM2,CLOCK)
      CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
      GO TO 230
C***********************************************************************
C**                        ENTER WORKABLE QUEUE                       **
C***********************************************************************
220   JOBWK = JOBWK+1
      HRWK = HRWK+JOB(1)
      NOJOB = 0
      DJOB = JOB(1)/10
      TIME = DJOB
      JOB(2) = JOB(1)-DJOB
      JOB(3) = 0
      CALL PUT(WQF,WQL,0,TIME,RFLOW,EMPTY)
230   THOURS = THOURS+JOB(1)
      IF(THOURS.LE.HOURS) GO TO 210
C***********************************************************************
C**                       START SIMULATION                            **
C***********************************************************************
240   DAY = 0
      TIMER = 0
      IF(CLOCK.NE.0.0) GO TO 280
C***********************************************************************
C**                 PUT END OF DAY INDICATOR ON EVENT CHAIN           **
C***********************************************************************
      JOB(1) = -1
      TIME = 80.001
      JOB(2) = 0
      JOB(3) = 0
      CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
280   PNT = WRKF
290   IF(REMAIN(PNT).NE.-1) GO TO 300
      CALL TIDLE(SUM,CLOCK,0,PNT,IDLTM,ITR,TOTIDL)
      IDLE = IDLE+1
300   PNT = DIRECT(PNT)
      IF(PNT.NE.0) GO TO 290
310   PNT = WRKF
      DO 315 J=1,SUM
      IF(IDLE .EQ.0) GO TO 320
      IF(NOJOB.EQ.1) GO TO 320
      IF(REMAIN(PNT).NE.-1) GO TO 315
      CALL NEWJOB(PNT,WQF,WQL,NWQF,NWQL,EMPTY,JOBWK,HRWK,
     *            CLOCK,NOJOB,IDLE,SUM,IDLTM,ITR,TOTIDL)
315   PNT = DIRECT(PNT)
C***********************************************************************
C**                   UPDATE CLOCK                                    **
C***********************************************************************
320   CLOCK = EVENT(NWQF)
C***********************************************************************
C**                   TAKE FIRST EVENT AND TEST FOR TYPE              **
C***********************************************************************
```

```
          CALL GET(NWQF,NWQL,TIME,RFLOW,EMPTY,STATUS)
          IF(JOB(1).EQ.-1) GO TO 525
          IF(JOB(3).EQ.-1) GO TO 425
          IF(JOB(2).EQ. 0) GO TO 475
          IF(JOB(3).EQ.-2) GO TO 500
          IF(RAN(I1,I2).GT.P2) GO TO 450
C***********************************************************************
C**                  JOB GOES NON-WORKABLE FROM IN PROCESS            **
C***********************************************************************
          PNT = JOB(3)
          JOB(3) = -2
          CALL DELAY(TIME,I1,I2,LAM1,LAM2,CLOCK)
          JOBNWK = JOBNWK+1
          HRNWK = HRNWK+JOB(2)
          CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
          GO TO 350
C***********************************************************************
C**                  JOB GOES FROM NON-WORKABLE TO WORKABLE           **
C***********************************************************************
  425     DJOB = JOB(1)/10
          TIME = DJOB
          JOB(2) = JOB(1)-DJOB
          JOBNWK = JOBNWK-1
          HRNWK = HRNWK-JOB(1)
          CALL PUT(WQF,WQL,1,TIME,RFLOW,EMPTY)
          NOJOB = 0
          JOBWK = JOBWK+1
          HRWK = HRWK+JOB(1)
          GO TO 310
C***********************************************************************
C**                  JOB STAYS IN PROCESS UNTIL COMPLETION            **
C***********************************************************************
  450     DUMMY = JOB(2)/EVENT(JOB(3))
          TIME = CLOCK+DUMMY
          JOB(2) = 0
          REMAIN(JOB(3)) = EMPTY
          CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
          GO TO 320
C***********************************************************************
C**                        JOB IS COMPLETED                           **
C***********************************************************************
  475     PNT = JOB(3)
          HRDONE = HRDONE+JOB(1)
          JCOMP = JCOMP+1
          TOTFLO = TOTFLO+CLOCK-RFLOW
          SQFLOW = SQFLOW+(CLOCK-RFLOW)**2
C***********************************************************************
C**                   GIVE FREED WORKER NEW JOB                       **
C***********************************************************************
  500     REMAIN(PNT) = -1
          IDLE = IDLE+1
          CALL ITIDLE(SUM,CLOCK,0,PNT,IDLTM,ITR,TOTIDL)
          CALL NEWJOB(PNT,WQF,WQL,NWQF,NWQL,EMPTY,JOBWK,HRWK,
     *               CLOCK,NOJOB,IDLE,SUM,IDLTM,ITR,TOTIDL)
```

```
            GO TO 320
      C*********************************************************************
      C**      JOB RETURNS FROM NON WORKABLE QUEUE FOR COMPLETION           **
      C*********************************************************************
      500   CALL PUT(WQF,WQL,1,TIME,RFLOW,EMPTY)
            NOJOB = 0
            JOBNWK = JOBNWK-1
            HRNWK = HRNWK-JOB(2)
            JOBWK = JOBWK+1
            HRWK = HRWK+JOB(1)
            GO TO 310
      C*********************************************************************
      C**                       SHIFT IS OVER                              *
      C*********************************************************************
      C**                 DETERMINE OVERTIME HOURS                          
      C*********************************************************************
      525   DAY = DAY+1
            TIMER = TIMER+80
            DHR = OVRTM/SUM
            ZIP = 10
            IF(DHR.GT.(6-DAY)) ZIP = 20
            TIME = CLOCK+240.0
            CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
            CLOCK = CLOCK-0.001
      C*********************************************************************
      C**                  FINISH WORK FOR THE DAY                          *
      C*********************************************************************
            PNT = WRKF
            DO 660 M=1,SUM
            RTIME = CLOCK
            IF(REMAIN(PNT).EQ.-1) GO TO 650
            IF(OVRTM.EQ.1) ZIP = 10
            IF(OVRTM.EQ.0) ZIP = 0
            RTIME = RTIME+ZIP
            WROW = REMAIN(PNT)
            RDIF = EVENT(WROW)-CLOCK-ZIP
            OVRTM = OVRTM-ZIP/10
            IF(RDIF.LE.0.0)  GO TO 550
            IF(WROW.NE.NWQF) GO TO 530
            CALL TAKE(NWQF,NWQL,TIME,RFLOW,EMPTY,STATUS)
            TIME = TIME+160-ZIP
            CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
            GO TO 660
      530   PNT1 = NWQF
      535   PNT2 = DIRECT(PNT1)
            IF(REMAIN(PNT).EQ.PNT2) GO TO 540
            PNT1 = PNT2
            GO TO 535
      540   TIME = EVENT(PNT2)+160-ZIP
            CALL RESORT(PNT,PNT1,PNT2,EMPTY,NWQF,NWQL,TIME)
            GO TO 660
      C*********************************************************************
      C**           JOB IS COMPLETED DURING OVERTIME HOURS                  **
      C*********************************************************************
```

```
 550   IF(WROW.NE.NWQF) GO TO 560
       CALL TAKE(NWQF,NWQL,TIME,RFLOW,EMPTY,STATUS)
       GO TO 600
 560   PNT1 = NWQF
 565   PNT2 = DIRECT(PNT1)
       IF(REMAIN(PNT).EQ.PNT2) GO TO 570
       PNT1 = PNT2
       GO TO 565
 570   DIRECT(PNT1) = DIRECT(PNT2)
       DIRECT(PNT2) = EMPTY
       EMPTY = PNT2
 600   HRDONE = HRDONE+JOBSIZ(WROW)
       JCOMP = JCOMP+1
       TOTFLO = TOTFLO+ CLOCK+ZIP-FLOW(WROW)
       SQFLOW = SQFLOW+(CLOCK+ZIP-FLOW(WROW))**2
       REMAIN(PNT) = -1
       IDLE = IDLE+1
       ATIME = CLOCK+ZIP+RDIF
       CALL TIDLE(SUM,ATIME,0,PNT,IDLTM,ITR,TOTIDL)
       CALL NEWJOB(PNT,WQF,WQL,NWQF,NWQL,EMPTY,JOBWK,HRWK,
     *                ATIME,NOJOB,IDLE,SUM,IDLTM,ITR,TOTIDL)
C***********************************************************************
C**     MODEL ASSUMES THAT THE PROBABILITY OF A JOB BEING STARTED      **
C**     AND COMPLETED IN THE SAME OVERTIME PERIOD IS 0.
C***********************************************************************
       IF(REMAIN(PNT).EQ.NWQF) GO TO 630
       IF(REMAIN(PNT).EQ.  -1) GO TO 650
       PNT1 = NWQF
 610   PNT2 = DIRECT(PNT1)
       IF(REMAIN(PNT).EQ.PNT2) GO TO 620
       PNT1 = PNT2
       GO TO 610
 620   TIME = EVENT(PNT2)+160.0-ZIP
       CALL RESORT(PNT,PNT1,PNT2,EMPTY,NWQF,NWQL,TIME)
       GO TO 660
 630   CALL TAKE(NWQF,NWQL,TIME,RFLOW,EMPTY,STATUS)
       TIME = TIME+160.0-ZIP
       CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
       GO TO 660
 650   CALL TIDLE(SUM,RTIME,1,PNT,IDLTM,ITR,TOTIDL)
       IDLE = IDLE-1
 660   PNT = DIRECT(PNT)
       CLOCK = CLOCK+160.0
       IF(TIMER.EQ.1040) GO TO 700
       TIMER = TIMER+160
       GO TO 280
C***********************************************************************
C**                    WEEK IS OVER                                    **
C***********************************************************************
 700   CHRDNE = HRDONE-THRDNE
       THRDNE = HRDONE
       AVFLOW = 0
       IF(JCOMP.NE.JBWK) AVFLOW = (TOTFLO-PREFLO)/(JCOMP-JBWK)/240.0
       PREFLO = TOTFLO
```

```
          JOBWK = JCOMP
          IF(FLAG.EQ.1) GO TO 90
          CALL OUTPUT(JOBWK,HRWK,JOBNWK,HRNWK,CHRDNE,WEEK,SUM,
         *                 IDLTM,AVFLOW)
    710   TYPE 711
    711   FORMAT(// DO YOU WISH TO OPERATE ANOTHER WEEK? (Y/N) ',$)
          ACCEPT 727,REPLY
    727   FORMAT(A4)
          IF(REPLY.EQ.YES) GO TO 100
          IF(REPLY.EQ. NO) GO TO 800
          GO TO 710
    800   RHOUR = (HRDONE-RHOUR)/10.0
          TOTIDL = TOTIDL/10.0
          AVFLOW = (TOTFLO-RDFLOW)/(JCOMP*240.0)
          SDFLOW = SQRT((SQFLOW-RSQFLO-JCOMP*(TOTFLO-RDFLOW))/
         *           (JCOMP-1))/240.0
          CALL FINAL(JCOMP,RHOUR,TOTIDL,WEEK,AVFLOW,SDFLOW)
          STOP
    810   MAXJOB = JOBWK+JOBNWK
          WRITE(6,815) MAXJOB
    815   FORMAT('OMAXIMUIM JOB LIMIT EXCEEDED. ',I4,' JOBS IN SHOP')
          STOP
          END
```

```
              SUBROUTINE INPUT(P1,P2,I1,I2,DMEAN,DSTDEV,NWK,EFF,MNJOB,M)
        C******************************************************************
        C**     SUBROUTINE INPUT ALLOWS THE OPERATOR TO ENTER THE INITIAL   *
        C**     PARAMETERS AND CONSTRAINTS.                                 *
        C**     FOR A DEFINITION OF THE VARIABLES SEE THE MAIN PROGRAM.     *
        C******************************************************************
              REAL LAM1,LAM2,MNJOB
              DIMENSION EFF(6)
        5     TYPE 6
        6     FORMAT(/' INPUT PROBABILITY JOB IS DETERMINED'
             *         ' NON-WORKABLE UPON ENTERING SHOP.  ',$)
              READ(6,10,ERR=5) P1
        10    FORMAT(F5.4)
        15    TYPE 16
        16    FORMAT(/' INPUT PROBABILITY JOB GOES NON-WORKABLE'/
             *         ' AFTER START OF PROCESSING. ',$)
              READ(6,10,ERR=15) P2
        20    TYPE 21
        21    FORMAT(/' INPUT MEAN DELAY IF JOB GOES NONWORKABLE IN DAYS'/
             *         ' (MUST INCLUDE DECIMAL POINT [EXAMPLE "3.0"])  ',$)
              READ(6,22,ERR=20) DMEAN
        22    FORMAT(F10.0)
        25    TYPE 26
        26    FORMAT(/' INPUT STANDARD DEVIATION OF DELAY TIME. (MUST'
             *         ' INCLUDE DECIMAL POINT.    ',$)
              READ(6,22,ERR=25) DSTDEV
        30    TYPE 31
        31    FORMAT(/' INPUT INTEGER (ODD) SEED FOR RANDOM'/
             *         ' NUMBER GENERATOR. (I3 FORMAT) ',$)
              READ(6,32,ERR=30) I1
        32    FORMAT(I3)
              I2 = I1
        40    TYPE 41
        41    FORMAT(/' INPUT AVERAGE JOB SIZE IN STANDARD MAN-HOURS'/
             *         ' (MUST INCLUDE DECIMAL POINT) ',$)
              READ(6,45,ERR=40) MNJOB
        45    FORMAT(F6.2)
        60    TYPE 61
        61    FORMAT(/' INPUT NUMBER OF WEEKS UNTIL TRANSFERED PERSONNEL'/
             *         ' ADJUSTED AND WORKING FULL EFFICIENCY. (I3 FORMAT) ',$)
              READ(6,32,ERR=60) NWK
        65    TYPE 66
        66    FORMAT(/' INPUT EFFICIENCY RATING OF TRANSFERED WORKER'/
             *         ' FOR FIRST WEEK IN SHOP. (IF WORKER IS'/
             *         ' EXPECTED TO WORK AT 80% EFFICIENCY THEN'/
             *         ' EFFICIENCY RATING IS 0.80)  ',$)
              READ(6,10,ERR=65) EFF(1)
              M = 1
        74    IF(M.GE.NWK-1) GO TO 77
              M = M+1
        75    TYPE 76
        76    FORMAT(/' INPUT EFFICIENCY RATING FOR THE NEXT WEEK. ',$)
              READ(6,10,ERR=[illegible]) EFF(M)
              GO TO 74
```

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81      TYPE 81
        FORMAT(' INPUT EFFICIENCY RATING FOR THIS WEEK AGAIN. ',$)
        GO TO 75
        EFF(NWK) = 1.0
50      TYPE 51
51      FORMAT(' INPUT NUMBER OF WORKERS IN SHOP AT START',
       *       ' OF SIMULATION. (I3 FORMAT) ',$)
        READ(6,32,ERR=50) NORMEN
        RETURN
        END
```

SHOP,SHOP=SHOP

```
      SUBROUTINE DATA(P1,P2,I1,I2,DMEAN,DSTDEV,NWK,MNJOB,NORMEN,EFF)
C*************************************************************************
C**   SUBROUTINE DATA IS USED TO INPUT THE INITIAL PARAMETERS           **
C**   FROM A STORED DATA FILE.                                          **
C**    FOR A DEFINITION OF THE VARIABLES SEE THE MAIN PROGRAM.          **
C*************************************************************************
      REAL MNJOB
      DIMENSION EFF(6)
      READ(3,5,ERR=25) P1,P2,DMEAN,DSTDEV,NWK,MNJOB
5     FORMAT(2(2X,F5.4),14X,2(2X,F10.3),2X,I3,2X,F6.2)
      READ(3,10,ERR=25) (EFF(J),J=1,6)
10    FORMAT(2X,6F4.2)
C************************************************************************
C**     USE CLOCK TO FIND RANDOM SEED FOR RANDOM NUMBER GENERATOR      **
C************************************************************************
      I1 = SECNDS(0.)/3.0
      IF(MOD(I1,2).EQ.0) I1 = I1 + 1
      I2 = I1
15    TYPE 16
16    FORMAT(/' INPUT NUMBER WORKERS IN SHOP AT START OF',
     *          ' SIMULATION. ',$)
      READ(6,20,ERR=15) NORMEN
20    FORMAT(I5)
      RETURN
25    TYPE 26
26    FORMAT(/' ERROR IN FILE 'DATA.DAT', CHECK FILE.')
      STOP
      END
```

```
SHOP,SHOP=SHOP

0001          SUBROUTINE PARAM(DMEAN,DSTDEV,LAM1,LAM2)
        C*********************************************************************
        C**   SUBROUTINE CALCULATES THE PARAMETERS FOR THE DELAY TIME       **
        C**   DISTRIBUTION.                                                 **
        C*********************************************************************
0002          REAL*8 A,B
0003          REAL LAM1,LAM2
        C*********************************************************************
        C**                  CALCULATE COEFFICIENT OF VARIANCE              **
        C*********************************************************************
0004          COVAR = DSTDEV/DMEAN
0005          IF(COVAR.GE.0.99) GO TO 20
0007          IF(COVAR.LE.0.71) GO TO 30
        C*********************************************************************
        C**             FIND PARAMETERS OF GENERAL TWO-STAGE ERLANG         **
        C*********************************************************************
0009          A = DMEAN/(DMEAN**2-DSTDEV**2)
0010          B = SQRT(2*DSTDEV**2-DMEAN**2)/(DMEAN**2-DSTDEV**2)
0011          LAM1 = A-B
0012          LAM2 = A+B
0013          RETURN
        C*********************************************************************
        C**                   FIND PARAMETERS OF EXPONENTIAL                **
        C*********************************************************************
0014    20    DUMI = 1.0/DMEAN
0015          LAM2 = 100.0*DUMI
0016          LAM1 = LAM2/(DMEAN*LAM2-1.0)
0017          RETURN
        C*********************************************************************
        C**          FIND PARAMETERS OF SPECIAL TWO-STAGE ERLANG.           **
        C*********************************************************************
0018    30    LAM1 = 2.0/DMEAN
0019          LAM2 = LAM1
0020          RETURN
0021          END
```

SHOP,SHOP=SHOP

```
      SUBROUTINE DELETE(WQF,WQL,NWQF,NWQL,WRKF,WRKL,EMPTY,CLOCK,
     *                      IDLE,JOBWK,HRWK)
C*************************************************************************
C**   SUBROUTINE DELETES WORKERS FROM THE SHOP AND PUTS ANY WORK        **
C**   LEFT BACK ON THE WORKABLE BACKLOG.                                **
C*************************************************************************
      IMPLICIT INTEGER (A-Z)
      REAL EVENT,CLOCK,TIME,HRWK,FLOW,RFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *       DIRECT(1000),WORK(1000),JOB(3)
      IF(WRKF.EQ.WRKL) GO TO 50
C*************************************************************************
C**               FIND WORKER'S LOCATION IN LIST.                       **
C*************************************************************************
      PNTA = WRKF
 5    PNTB = DIRECT(PNTA)
      IF(DIRECT(PNTB).EQ.0) GO TO 10
      PNTA = PNTB
      GO TO 5
C*************************************************************************
C**               REMOVE WORKER AND UPDATE POINTERS.                    **
C*************************************************************************
 10   DIRECT(PNTA) = 0
      WRKL = PNTA
      DIRECT(PNTB) = EMPTY
      EMPTY = PNTB
      IF(REMAIN(PNTB).EQ.-1) GO TO 40
      PNT1 = REMAIN(PNTB)
      IF(PNT1.EQ.NWQF) GO TO 25
      PNT2 = NWQF
 15   PNT3 = DIRECT(PNT2)
      IF(PNT3.EQ.PNT1) GO TO 20
      PNT2 = PNT3
      GO TO 15
C*************************************************************************
C**         PUT UNFINISHED JOB BACK ON WORKABLE BACKLOG.                **
C*************************************************************************
 20   JOB(1) = JOBSIZ(PNT3)
      JOB(2) = REMAIN(PNT3)
      JOB(3) = WORK(PNT3)
      TIME = EVENT(PNT3)
      RFLOW = FLOW(PNT3)
      DIRECT(PNT2) = DIRECT(PNT3)
      DIRECT(PNT3) = EMPTY
      EMPTY = PNT3
      IF(DIRECT(PNT2).EQ.0) NWQL=PNT2
      GO TO 30
 25   CALL TAKE(NWQF,NWQL,TIME,RFLOW,EMPTY,STATUS)
 30   TIME = TIME-CLOCK
      DUMMY = TIME*EVENT(JOB(3))
      IF(JOB(2).EQ.0) GO TO 35
      TIME = DUMMY
      JOB(3) = -2
      CALL PUT(WQF,WQL,1,TIME,RFLOW,EMPTY)
```

```
          JOBWK = JOBWK+1
          HRWK = HRWK+JOB(1)
          RETURN
    35    JOB(2) = DUMMY
          JOB(3) = -1
          CALL PUT(WQF,WQL,1,TIME,RFLOW,EMPTY)
          JOBWK = JOBWK+1
          HRWK = HRWK+JOB(1)
          RETURN
C*************************************************************************
C**                         WORKER WAS IDLE.                            **
C*************************************************************************
    40    IDLE = IDLE-1
          RETURN
    50    TYPE 51
    51    FORMAT(// ALL WORKERS DELETED.  PROGRAM TERMINATED.')
          STOP
          END
```

SHOP,SHOP=SHOP

```
      SUBROUTINE DELAY(TOTAL,I,J,PAR1,PAR2,TIME)
C************************************************************************
C**    SUBROUTINE DETERMINES DELAY TIME FOR A JOB ENTERING THE        **
C**    NON-WORKABLE QUEUE.  DELAY TIME IS ADJUSTED SO THAT NO         **
C**    JOBS CAN COME OFF THE QUEUE AT NIGHT.                           **
C**    VARIABLES ARE AS DEFINED IN MAIN PROGRAM.                       **
C************************************************************************
5     INTER = (-ALOG(RAN(I,J))/PAR1-ALOG(RAN(I,J))/PAR2)*240
      IF(INTER.GT.4800) GO TO 5
      TOTAL = INTER+TIME
      REM = AMOD(TOTAL,240.0)
      IF(REM.GT.80.0) GO TO 10
      RETURN
10    TOTAL = TOTAL+240-REM
      RETURN
      END
```

```
SHOP,SHOP=SHOP

          SUBROUTINE PUT(FROW,LROW,SORT,REAL,RFLOW,SPACE)
C*****************************************************************************
C**   SUBROUTINE PUT IS USED TO PUT AN ENTRY ONTO THE LIST.  ENTRIES         **
C**   CAN BE INSERTED ON EITHER END OF THE LIST OR INTO THE MIDDLE.          **
C**    SORT = VARIABLE WHICH DETERMINES TYPE OF INSERTION.                   **
C**           IF 0 THEN ENTRY IS PUT ONTO BACK OF LIST.                      **
C**           IF 1  "    "    "  "    "  FRONT OF LIST.                      **
C**           IF 2 ENTRY IS SORTED INTO THE LIST SO THAT IT IS IN            **
C**           FRONT OF THE FIRST LARGER ENTRY.                               **
C*****************************************************************************
      IMPLICIT INTEGER (A-Z)
      REAL EVENT,FLOW,REAL,RFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *       DIRECT(1000),WORK(1000),JOB(3)
C*****************************************************************************
C**          DETERMINE WHERE ENTRY GOES;FIRST,LAST,OR SORTED.                **
C*****************************************************************************
      IF (FROW.EQ.0) GO TO 50
      IF (SORT.EQ.0) GO TO 40
      IF (SORT.EQ.1) GO TO 30
C*****************************************************************************
C**            SORT LIST TO FIND WHERE ENTRY GOES.                           **
C*****************************************************************************
      PNT1 = FROW
      IF (EVENT(PNT1).GT.REAL) GO TO 30
10    PNT2 = DIRECT(PNT1)
      IF (PNT2.EQ.0) GO TO 40
      IF (EVENT(PNT2).GT.REAL) GO TO 20
      PNT1 = PNT2
      GO TO 10
C*****************************************************************************
C**              PUT ENTRY INTO MIDDLE OF LIST.                              **
C*****************************************************************************
20    JOBSIZ(SPACE) = JOB(1)
      EVENT(SPACE) = REAL
      FLOW(SPACE) = RFLOW
      REMAIN(SPACE) = JOB(2)
      WORK(SPACE) = JOB(3)
      ZZ = SPACE
      SPACE = DIRECT(SPACE)
      DIRECT(PNT1) = ZZ
      DIRECT(ZZ) = PNT2
      RETURN
C*****************************************************************************
C**              PUT ENTRY ONTO FRONT OF LIST.                               **
C*****************************************************************************
30    PNT = FROW
      FROW = SPACE
      JOBSIZ(FROW) = JOB(1)
      EVENT(FROW) = REAL
      FLOW(FROW) = RFLOW
      REMAIN(FROW) = JOB(2)
      WORK(FROW) = JOB(3)
      SPACE = DIRECT(SPACE)
```

```
      DIRECT(FROW) = PNT
      RETURN
C**********************************************************************
C**             PUT ENTRY ONTO END OF LIST.                          **
C**********************************************************************
 40   PNT = LROW
      LROW = SPACE
      JOBSIZ(LROW) = JOB(1)
      EVENT(LROW) = REAL
      FLOW(LROW) = RFLOW
      REMAIN(LROW) = JOB(2)
      WORK(LROW) = JOB(3)
      SPACE = DIRECT(SPACE)
      DIRECT(PNT) = LROW
      DIRECT(LROW) = 0
      RETURN
C**********************************************************************
C**           ENTRY IS FIRST IN LIST SETUP IS REQUIRED.              **
C**********************************************************************
 50   FROW = SPACE
      LROW = SPACE
      JOBSIZ(FROW) = JOB(1)
      EVENT(FROW) = REAL
      FLOW(FROW) = RFLOW
      REMAIN(FROW) = JOB(2)
      WORK(FROW) = JOB(3)
      SPACE = DIRECT(SPACE)
      DIRECT(FROW) = 0
      RETURN
      END
```

SHOP,SHOP=SHOP

```
      SUBROUTINE TAKE(FROW,LROW,AREAL,RFLOW,SPACE,STATUS)
C**********************************************************************
C**   SUBROUTINE TAKE IS USED TO REMOVE AN ENTRY IN THE LIST.        **
C**   VACANCY IS THEN DESIGNATED AS FIRST AVAILABLE EMPTY SPACE.     **
C**   STATUS IS A FLAG, WHEN THERE ARE NO JOBS IN THE LIST IT IS     **
C**   SET TO '0'.  OTHERWISE IT IS SET TO '1'.                       **
C**********************************************************************
      IMPLICIT INTEGER(D-Z)
      REAL EVENT,FLOW,RFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *      DIRECT(1000),WORK(1000),JOB(3)
      STATUS = 1
      IF(FROW.EQ.0) GO TO 15
C***** TRANSFER INFORMATION ON ENTRY *****************************
      JOB(1) = JOBSIZ(FROW)
      AREAL = EVENT(FROW)
      RFLOW = FLOW(FROW)
      JOB(2) = REMAIN(FROW)
      JOB(3) = WORK(FROW)
C****** UPDATE POINTERS *********************************************
      PNT = DIRECT(FROW)
      DIRECT(FROW) = SPACE
      SPACE = FROW
      FROW = PNT
      IF(FROW.EQ.0) GO TO 15
      RETURN
 15   STATUS = 0
      LROW = 0
      RETURN
      END
```

```
SHOP,SHOP=SHOP

      SUBROUTINE NEWJOB(PNT,WQF,WQL,NWQF,NWQL,EMPTY,JOBWK,HRWK,
     *                    CLOCK,NOJOB,IDLE,SUM,IDLTM,ITR,TOTIDL)
C**********************************************************************
C**   SUBROUTINE GIVES WORKER A NEW JOB FROM THE WORKABLE QUEUE.     **
C**   VARIABLES ARE AS DEFINED IN THE MAIN PROGRAM.                  **
C**********************************************************************
      IMPLICIT INTEGER(A-Z)
      REAL EVENT,TIME,CLOCK,IDLTM,HRWK,FLOW,RFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *       DIRECT(1000),WORK(1000),JOB(3)
      IF(NOJOB.EQ.1) RETURN
      CALL TIDLE(SUM,CLOCK,1,PNT,IDLTM,ITR,TOTIDL)
      IDLE = IDLE-1
      CALL TAKE(WQF,WQL,TIME,RFLOW,EMPTY,STATUS)
      IF(STATUS.EQ.0) NOJOB=1
      JOBWK = JOBWK-1
      HRWK = HRWK-JOB(1)
      IF(JOB(3).NE.-2)GO TO 20
C**********************************************************************
C**            JOB HAS ALREADY BEEN IN-PROCESS BEFORE                **
C**********************************************************************
      DUMMY = JOB(2)/EVENT(PNT)
      TIME = DUMMY+CLOCK
      JOB(2) = 0
 10   JOB(3) = PNT
      REMAIN(PNT) = EMPTY
      CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
      RETURN
C**********************************************************************
C**             JOB HAS NOT BEEN IN-PROCESS BEFORE                   **
C**********************************************************************
 20   DUMMY = TIME/EVENT(PNT)
      TIME = DUMMY+CLOCK
      GO TO 10
      END
```

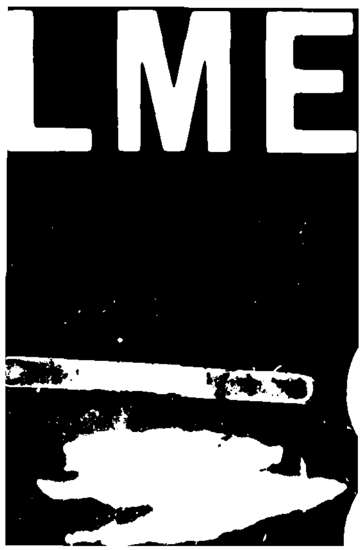
```
      SUBROUTINE TIDLE(SUM,CLOCK,FLAG1,PNT,IDLTM,ITR,TOTIDL)
C*************************************************************************
C**         SUBROUTINE DETERMINES AMOUNT OF WORKER IDLE TIME.          **
C*************************************************************************
      IMPLICIT INTEGER (D-Z)
      REAL IDLTM,EVENT,TOTIDL,FLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *       DIRECT(1000),WORK(1000),JOB(3)
      DIMENSION IFLAG(100),BTIME(100)
      IF(SUM.GT.ITR) ITR = SUM
 5    IF(FLAG1.EQ.1) GO TO 20
C*************************************************************************
C**                      WORKER STARTS IDLE PERIOD.                    **
C*************************************************************************
      DO 10 I=1,ITR
      IF(IFLAG(I).EQ.0) GO TO 15
 10   CONTINUE
 15   IFLAG(I) = 1
      BTIME(I) = CLOCK
      WORK(PNT) = I
      RETURN
C*************************************************************************
C**                      WORKER ENDS IDLE PERIOD                       **
C*************************************************************************
 20   I = WORK(PNT)
      IDLTM = IDLTM+CLOCK-BTIME(I)
      TOTIDL = TOTIDL+CLOCK-BTIME(I)
      IFLAG(I) = 0
      RETURN
      END
```

```
      SUBROUTINE RESORT(PNT,PNT1,PNT2,EMPTY,NWQF,NWQL,TIME)
C*****************************************************************************
C**     SUBROUTINE TAKES THE ENTRY AT ROW 'PNT2' , CHANGES THE              **
C**     EVENT TIME AND THEN INSERTS IT BACK ONTO THE LIST.                  **
C*****************************************************************************
      IMPLICIT INTEGER (A-Z)
      REAL EVENT,TIME,FLOW,RFLOW
      COMMON EVENT(1000),FLOW(1000),JOBSIZ(1000),REMAIN(1000),
     *       DIRECT(1000),WORK(1000),JOB(3)
      JOB(1) = JOBSIZ(PNT2)
      JOB(2) = REMAIN(PNT2)
      JOB(3) = WORK(PNT2)
      RFLOW = FLOW(PNT2)
      DIRECT(PNT1) = DIRECT(PNT2)
      DIRECT(PNT2) = EMPTY
      EMPTY = PNT2
      IF(PNT2.EQ.NWQL) NWQL = PNT1
      CALL PUT(NWQF,NWQL,2,TIME,RFLOW,EMPTY)
      REMAIN(PNT) = PNT2
      RETURN
      END
```

```
SHOP,SHOP=SHOP

              SUBROUTINE OUTPUT(JOBWK,HRWK,JOBNWK,HRNWK,DONE,WEEK,SUM,
         *                        IDLTM,AVFLOW)
      C**********************************************************************
      C**     SUBROUTINE OUTPUTS THE STATE OF THE SYSTEM AT THE END OF THE   *
      C**     WEEK.  VARIABLES ARE AS DEFINED IN THE MAIN PROGRAM.           *
      C**********************************************************************
              IMPLICIT INTEGER(A-Z)
              REAL EVENT,CLOCK,IDLTM,HRWK,HRNWK,DONE,WDONE,HW,HNW
              REAL*8 AVFLOW
              WDONE = DONE/10.0
              IDLTM = IDLTM/10.0
              HW = HRWK/10.0
              HNW = HRNWK/10.0
              WRITE(6,10)WEEK
        10    FORMAT(10(/),15X,'RESULTS FOR WEEK',I4//)
              WRITE(6,15)
        15    FORMAT(5X,'BACKLOG',10X,'NO. OF JOBS     NO. OF HOURS OF WO
              WRITE(6,20)
        20    FORMAT(5X,'=======',10X,11('='),5X,20('='))
              WRITE(6,25)JOBWK,HW,JOBNWK,HNW
        25    FORMAT(5X,'WORKABLE',I18,F19.1/5X,'NONWORKABLE',I15,F19.1/)
              WRITE(6,35) IDLTM
        35    FORMAT(5X,'WORKERS WERE IDLE ',F6.1,' HOURS'/)
              WRITE(6,30)WDONE
        30    FORMAT(5X,'WORK COMPLETED THIS WEEK TOTALLED ',F7.1,' HOURS.
              WRITE(6,36) AVFLOW
        36    FORMAT(5X,'AVERAGE FLOW TIME ',F6.1,' DAYS'/)
              WRITE(6,40) SUM
        40    FORMAT(5X,'NUMBER OF WORKERS IN SHOP IS ',I4/)
              RETURN
              END
```

```
              SUBROUTINE FINAL(JCOMP,RHOUR,TOTIDL,NWEEK,AVFLOW,SDFLOW)
        C***********************************************************************
        C**   SUBROUTINE OUTPUTS THE STATE OF THE SYSTEM AT THE END OF         **
        C**   SIMULATION.  SEE MAIN PROGRAM FOR DEFINITION OF VARIABLES.      **
        C***********************************************************************
              REAL*8 AVFLOW,SDFLOW
              WRITE(6,10) NWEEK
        10    FORMAT(10(/),10X,'FINAL RESULTS FOR',I3,' WEEKS'//)
              WRITE(6,15) JCOMP,RHOUR
        15    FORMAT(I10,' JOBS WERE COMPLETED TOTALLING',F7.1,
             *       ' HOURS OF WORK')
              WRITE(6,16) AVFLOW,SDFLOW
        16    FORMAT(/' AVERAGE FLOW TIME WAS ',F7.1,' DAYS WITH A'/
             *            ' STANDARD DEVIATION OF ',F7.1)
              WRITE(6,20) TOTIDL
        20    FORMAT(/' WORKERS WERE IDLE FOR ',F7.1,' HOURS.')
              STAT = RHOUR/(RHOUR+TOTIDL)*100.0
              WRITE(6,25) STAT
        25    FORMAT(/' SHOP OPERATED AT ',F5.1,'%'////)
              RETURN
              END
```


LME